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# **MAGNETOSTATIC WAVE DEVICE CHARACTERIZATION BY BRILLOUIN LIGHT SCATTERING**

**Colorado State University**

**Carl E. Patton and Gopalan Srinivasan**

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) This final report summarizes the important results of the Brillouin light scattering investigations of magnetic excitations in magnetostatic wave (MSW) devices which were carried out under the RADC contract. The key accomplishments were the observation and characterization of surface waves, forward volume waves, backward volume waves, parametric spin waves, and a new type of evanescent surface wave in yttrium iron garnet film MSW devices. The propagation characteristics for surface wave in Fe, Co-Cr, and Ni-Fe films were also examined, in order to investigate the possible use of such films in MSW devices. Details on technical publications and participating personnel during this contract period are also provided.						
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## I. INTRODUCTION

The main objective of this project on magnetostatic wave (MSW) device characterization by Brillouin light scattering (BLS) was to directly detect and characterize surface, forward volume and backward volume waves and parametric spin wave excitations in MSW device structures by light scattering techniques. The three-year proposal was funded by the Electromagnetics Directorate of the Rome Air Development Center. The study was initiated in February 1985 and a six-month extension was granted in February 1988.

A high contrast multipass-tandem Fabry-Perot interferometer was used for the observation of MSW excitations in a variety of yttrium iron garnet (YIG) film - MSW device structures such as signal-to-noise enhancers and delay lines. The technique was further used to characterize the excitations in terms of wavenumber and propagation angle and to measure the magnon dispersion and intensity profiles for the magnetic excitations. The BLS technique was also used to study the propagation characteristics for thermal surface magnons in thin films of Fe on GaAs, Cobalt-Chromium, and permalloy. Such studies were undertaken to explore the possible use of such films in MSW devices.

Dr. G. Srinivasan presented an invited talk at the Tokyo, Japan Intermag Conference, April, 1987 on the use of BLS techniques for the characterization of MSW devices. Professor C. E. Patton presented an invited talk on nonlinear microwave processes in ferrite materials at the Joint Intermag - MMM Conference, Vancouver, BC, Canada, in July, 1988.

Section II of this report summarized the important results from this contract topic by topic, and lists the pertinent publications connected with each topic. Section III provides a full list of publications on the contract. Section IV lists personnel supported on the contract in one form or another.

## II. RESULTS

### A. Observation of magnetic excitations in MSW devices:

In magnon scattering, the interaction between the incident light and magnons within the material gives rise to a frequency shift for the scattered light and the magnons are detected by measuring the intensity vs. frequency profile for the scattered light with a Fabry-Perot interferometer (FPI). The overall experimental setup used for the observation of MSW excitations in device structures is shown schematically in Fig. II-1. The forward scattering geometry in Fig. II-1 was essential for the detection of magnons with wavenumber less than  $10^4 \text{ cm}^{-1}$ . The FPI system has high contrast, in excess of  $10^{12}$ , and a finesse of 50. Such a high-sensitivity FPI system was crucial to the success of the measurements since the magnon scattering was often weak. The experiments were done on a signal-to-noise enhancer device (provided by J. D. Adam, Westinghouse) and a delay line device (provided by W. Ishak, HP).

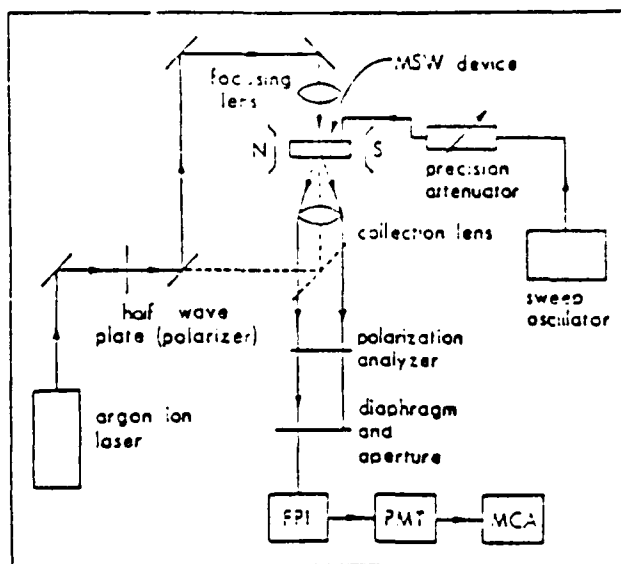


Fig.II-1: Block diagram of the Brillouin light scattering spectrometer system.

(i) Surface waves:

The BLS technique was successfully used to detect magnetostatic surface waves excited at 2 to 4 GHz in YIG films in a signal-to-noise enhancer device structure. Figure II-2 shows the Brillouin spectra for the surface waves at low powers and for the surface waves and half-frequency spin waves at high powers. The specific accomplishments in the BLS studies on surface waves are (i) determination of the propagation direction and dispersion character (wavenumber  $k$  vs. field), (ii) measurement of the  $k$ -distribution as a function of field and frequency, (iii) the observation of critical power effects and half-frequency spin waves which propagate in a plane perpendicular to the film plane, and (iv) measurements of intensity vs. field profile for the surface waves and parametric spin waves. Such profiles at 4 GHz are shown in Fig.II-3.

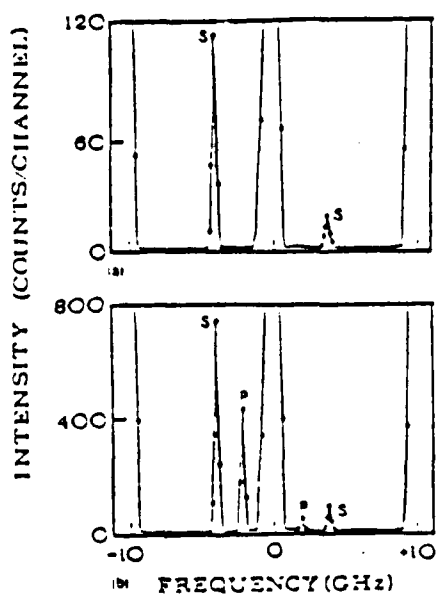
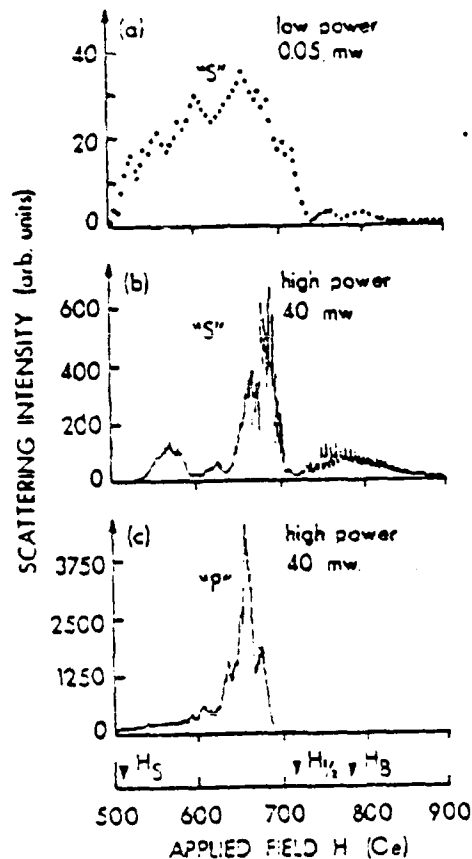


Fig.II-2: Brillouin light scattering spectra for at 4 GHz for (a) surface waves at low powers and (b) surface waves and half-frequency spin waves at high powers in a YIG film in a signal-to-noise enhancer MSW device.

Fig. II-3: Intensity vs static field profiles at 4 GHz for (a) surface waves at low powers and for (b) surface waves and (c) half frequency spin waves at high powers in a YIG film in a signal-to-noise enhancer MSW device.



"Direct Observation of Surface Wave Excitations in Magnetostatic Wave Devices", G. Srinivasan and C. E. Patton, IEEE Trans. Magn. MAG-21, 1797 (1985).

"Direct Detection of Magnetostatic Wave Excitations in Magnetostatic Wave Device Structures by Brillouin Light Scattering", G. Srinivasan and C. E. Patton, Appl. Phys. Lett. 47, 759 (1985).

"Brillouin Light Scattering on Yttrium Iron Garnet Films in a Magnetostatic Wave Device Structure", G. Srinivasan, C. E. Patton and P. R. Emtage, J. Appl. Phys. 61, 2318 (1987).

#### (ii) Volume Waves:

A considerable effort was directed to the study of forward volume and backward volume waves (BVW) in YIG films in signal-to-noise enhancers and delay line devices. The BVW excitations were studied over the frequency range 2 to 4 GHz. The observed BVW band limits were found to be in reasonable agreement with theory. The BLS data on magnon dispersion were

found to be in very good agreement with the theoretical dispersion. Figure II-4 shows the results of such dispersion measurements at 4 GHz.

"Characterization of Magnetostatic Wave Devices by Brillouin Light Scattering", G. Srinivasan, J. G. Booth, and C. E. Patton, IEEE Trans. Magn. MAG-23, 3718 (1987).

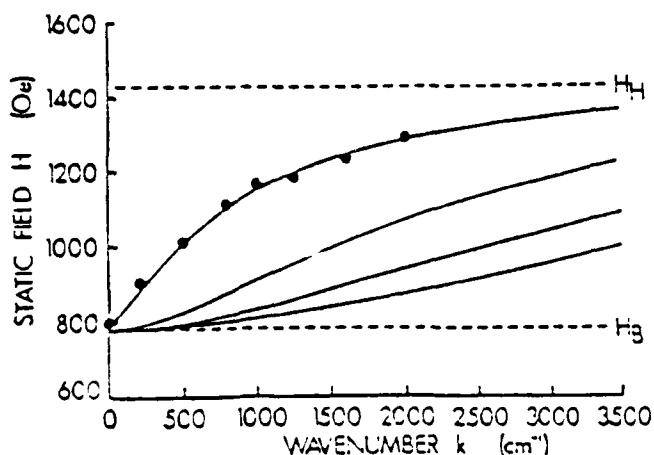


Fig. II-4: Data on field vs. wavenumber for BVW excitations propagating parallel to the applied field in a signal-to-noise enhancer device at 4 GHz. The solid lines represent the theoretical dispersion for the first four BVW branches.

(iii) Parametric spin waves:

A detailed BLS investigation was performed on parametric spin wave excitations in YIG films. The measurements on magnon wavenumber, propagation angle, threshold microwave field, and intensity vs. static field profile were done with stripline excitation at low frequency (3-6 GHz) and with cavity excitation at high frequency (8-10 GHz). Data on threshold field vs. static field were in good agreement with theory. The measurements at high frequencies showed magnon wavenumber  $k$  larger than  $k$ -values for the expected magnetostatic modes and the results did not show evidence for the predicted flip in the azimuthal propagation angle for the spin wave modes.

"Direct Observation of Surface Wave Excitations in Magnetostatic Wave Devices", G. Srinivasan and C. E. Patton, IEEE Trans. Magn. MAG-21, 1797 (1985).

"Brillouin Light Scattering on Yttrium Iron Garnet Films in a Magnetostatic Wave Device Structure", G. Srinivasan, C. E. Patton and P. R. Emtage, J. Appl. Phys. 61, 2318 (1987).

"Light scattering observation of anomalous parametric spin wave character in subsidiary absorption", W. D. Wilber, J. G. Booth, C. E. Patton, G. Srinivasan, and R. W. Cross, to be published in the joint MMM-INTERMAG conference proceedings issue of J. Appl. Phys., September 1988.



(iv) Evanescent surface magnons:

An important result of our light scattering studies on MSW device structures was the observation of a new type of localized spin wave excitation in YIG films. Such evanescent surface magnons were observed for static fields above the surface wave band edge in a signal-to-noise enhancer device. According to theory, the evanescent waves may be supported only in presence of a ground plane and the band width in field is proportional to the film-ground plane separation. The measured evanescent wave band edge was in good agreement with the theoretical value.

"Optical Observation of Evanescent Surface Magnons in Thin Magnetic Films", G. Srinivasan, P. R. Emtage, J. G. Booth, and C. E. Patton, J. Appl. Phys. 63, 3817 (1988).

B. Thermal surface magnons in metal films:

The propagation characteristics for thermal surface waves in thin films of Fe on GaAs, Co-Cr, and permalloy were studied with BLS techniques in order to investigate the possible use for such films in MSW devices. From light scattering data on magnon dispersion, it was possible to observe directly the exchange spin wave branch and magnetostatic surface wave branch crossover in Fe and Co-Cr films. The propagation angle (angle between in-plane static field and in-plane surface wave wave-vector) dependence of the magnon dispersion for surface waves was studied in permalloy films. The theory predicts a critical angle at which the surface wave branch merges with the top of the bulk spin wave mode. From BLS studies, the observed critical angle was found to be much larger than the theoretical value.

"Brillouin Light Scattering on Cobalt Chromium Films", G. Srinivasan and C. E. Patton, IEEE Trans. Magn. MAG-22, 996 (1986).

"Light Scattering Study on Surface Magnons in Permalloy films", G. Srinivasan and C. E. Patton, J. Appl. Phys. 61, 4120 (1987).

C. Chaos in spin wave instabilities:

Finally, BLS and microwave measurements were performed on auto-oscillations and chaos associated with spin wave instabilities at high microwave power levels in yttrium iron garnet. These phenomena appear to be fundamental to the nonlinear microwave dynamics in single crystal ferrite materials and may provide key information for understanding (i) the nature of the nonlinear interactions between parametric spin wave modes and (ii) the performance of nonlinear MSW devices. Our initial microwave measurements on subsidiary absorption in YIG films showed complicated dependences for (1) the auto-oscillation frequency and (2) the threshold microwave field amplitude for such oscillations as a function of the static field. At high powers, subharmonic bifurcations and chaos were observed. A program to use Brillouin light scattering to probe directly the nonlinear spin waves which give rise to the auto-oscillations and show chaotic behavior is just starting.

"Observation of auto-oscillations and chaos in subsidiary absorption in yttrium iron garnet", G. Srinivasan, M. Chen, and C. E. Patton, to be published in the joint MMM-INTERMAG conference proceedings issue of J. Appl. Phys., September 1988.

### III. PUBLICATIONS

1. "Direct Observation of Surface Wave Excitations in Magnetostatic Wave Devices", G. Srinivasan and C. E. Patton, IEEE Trans. Magn. MAG-21, 1797 (1985).
2. "Direct Detection of Magnetostatic Wave Excitations in Magnetostatic Wave Device Structures by Brillouin Light Scattering", G. Srinivasan and C. E. Patton, Appl. Phys. Lett. 47, 759 (1985).
3. "Brillouin Light Scattering on Cobalt Chromium Films", G. Srinivasan and C. E. Patton, IEEE Trans. Magn. MAG-22, 996 (1986).
4. "Light Scattering Study on Surface Magnons in Permalloy films", G. Srinivasan and C. E. Patton, J. Appl. Phys. 61, 4120 (1987).
5. "Measurement of the Spin Wave Instability Threshold  $h_{crit}$  in Microwave Ferrites", Y. T. Zhang, C. E. Patton, G. Srinivasan, G. O. White, C. J. Brower, and C. A. Edmondson, Rev. Sci. Instr. 58, 620 (1987).
6. "Brillouin Light Scattering on Yttrium Iron Garnet Films in a Magnetostatic Wave Device Structure", G. Srinivasan, C. E. Patton and P. R. Emtage, J. Appl. Phys. 61, 2318 (1987).
7. "Spin Wave Stiffness Parameters in Lithium-Zinc Ferrites" J. G. Booth, G. Srinivasan, C. E. Patton, and C. M. Srivastava, Solid State Commun. 64, 287 (1987).
8. "Brillouin Light Scattering Study of the Spin Wave Stiffness Parameter in Sc-Substituted Lutetium-Yttrium Iron Garnet", J. G. Booth, G. Srinivasan, C. E. Patton, and P. de Gasperis, IEEE Trans. Magn. MAG-23, 3494 (1987).
9. "Characterization of Magnetostatic Wave Devices by Brillouin Light Scattering", G. Srinivasan, J. G. Booth, and C. E. Patton, IEEE Trans. Magn. MAG-23, 3718 (1987).
10. "Optical Observation of Evanescent Surface Magnons in Thin Magnetic Films", G. Srinivasan, P. R. Emtage, J. G. Booth, and C. E. Patton, J. Appl. Phys. 63, 3817 (1988).
11. "The second-order spin-wave instability threshold in single-crystal yttrium-iron-garnet films under perpendicular pumping", Y. T. Zhang, C. E. Patton, and G. Srinivasan, J. Appl. Phys. 63, 5433 (1988).
12. "Brillouin Light Scattering Detection of Ferromagnetic Resonance in Thin Films", G. Srinivasan, C. E. Patton, and J. G. Booth, J. Appl. Phys. 63, 3344 (1988).

13. "Light scattering observation of anomalous parametric spin wave character in subsidiary absorption", W. D. Wilber, J. G. Booth, C. E. Patton, G. Srinivasan, and R. W. Cross, to be published in the joint MMM-INTERMAG conference proceedings issue of J. Appl. Phys., September 1988.
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#### IV PERSONNEL

The personnel supported on this project in one form or another (salary, materials, etc.) are listed below.

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